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Aperture Synthesis CO Observations of the Inner Disk of NGC 1068

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NGC 1068 is probably the nearest galaxy with both a high rate of star formation and a high luminosity active nucleus. About one-half of the total IR luminosity originates in a disk approximately 30$''$ in size, which has been taken as evidence for a high rate of massive star formation (Telesco *et al.* 1984). Previous CO line observations have shown the existence of a ring at the outer boundary of the inner disk (Myers and Scoville 1987). Although these observations have proved that this ring is extremely rich in molecular gas (as suggested by Scoville *et al.* 1983), the angular resolution ($\sim$6$''$) was not high enough to resolve its structure.

New aperture synthesis observations of the CO (J=1$\rightarrow$0) emission in the inner disk of NGC 1068 have been carried out with the OVRO mm Interferometer. The new receivers installed for the 88/89 season have allowed us to obtain a high sensitivity map of the CO emission. The molecular cloud ring has been resolved and continuum as well as line emission from the nucleus of the galaxy have been detected.

OBSERVATIONS

The observations were made from November 1988 to March 1989 with the Owens Valley Radio Observatory (OVRO) millimeter-wave interferometer. Spectral coverage was provided by a filter-bank consisting of 32 5-MHz channels giving a resolution of 13 km s^{-1} and a coverage of 416 km s^{-1} in the CO J=1$\rightarrow$0 transition. Radio continuum measurements in both sidebands were simultaneously obtained using $\sim$500 MHz continuum channels. NGC 1068 was observed in six different configurations with baselines out to 200 m east-west and 140 m north-south. The synthesized beam was 2.9$''$ $\times$ 2.9$''$, corresponding to a linear size of 260 pc at a distance of 18.1 Mpc (Sandage and Tammann 1975). The average rms was 60 mJy/beam in the 5 MHz channels, a factor of four lower than in previous observations done in 1986 with the same instrument.

RESULTS

The resulting contour map of the integrated CO intensity (in the range 917 to 1333 km s^{-1}) for NGC 1068 is shown in Figure 1. The shape and intensity of the CO emission distribution agree very well with the results of a previous observation (Myers and Scoville 1987) when convolved to a resolution of 5$''$ $\times$ 7$''$ or 7$''$ $\times$ 11$''$, showing two dominant emission peaks located at distances of 14$''$ north and south of the nucleus. The new higher resolution map shows a much more complex structure for the ring, with ten or more peaks of emission. Some of them seem to be originated in unresolved sources, but others extend to linear sizes of $\sim$600 pc, so they possibly correspond to complexes of giant molecular clouds.

The overall shape of the emission distribution closely matches that of a ring encircling the nucleus. Part of the emission extends out of such a ring, suggestive of the start of spiral arms. The

whole structure could equally well be constituted by two spiral arms, that start at the ends of the stellar bar found at 2.2 μm (Scoville *et al.* 1988) and they extend for at least 5 kpc in length and ~300 pc in width.

The total mass of the molecular gas detected in the ring feature may be estimated using the relation between integrated CO emission and molecular mass derived from observations of giant molecular clouds in our Galaxy. We use the relation $N_{H_2}/I_{CO} = 3.6\times10^{20}$ cm^2 (K km s^{-1})$^{-1}$. The total H_2 mass in the ring is approximately 3.8×10^9 $M_\odot$. This corresponds to ~25% of the total molecular mass of the galaxy as derived from single dish observations (Scoville, Young, and Lucy 1983; Planesas, Gomez-Gonzales, and Martin-Pintado 1989).

A very good spatial correlation exists between the CO distribution and the 10.8 μm emission determined by Telesco and Decher (1988). Almost all the IR peaks lay very close to CO peaks of emission, which supports the interpretation of the disk IR emission as originating from young massive stars. In some regions (west, southeast), however, CO emission exists without any IR counterpart.

Radio continuum emission from the nucleus has been clearly detected at 2.6 mm in both sidebands. The northeast lobe of the radio jet has also been detected in the lower sideband because of the lower noise level at this frequency. The intensity of the central peak (31 mJy/beam) is consistent with the fluxes and spectral index measured at 15 and 22 GHz (Ulvestad, Neff, and Wilson 1987). The flux measured in the upper sideband is significantly larger (50 mJy/beam), which might indicate that a substantial contribution to this flux comes from CO molecular emission from the nucleus. If so, an estimate of the H_2 mass of 8×10^7 $M_\odot$ is derived assuming that the same N_{H_2}/I_{CO} can be applied to the gas located in the nucleus, although the physical conditions of the molecular gas in the nucleus of NGC 1068 and in the giant molecular clouds in our galaxy are probably different. In fact, the dust temperature in the center of NGC 1068 is ~ 40 K (Young and Sanders 1986), so the value given for the mass should be considered as an upper limit. If the molecular gas is uniformly distributed in a 260 pc diameter sphere, an average density of 175 H_2 cm^{-3} and a peak extinction of 140 mag are deduced.

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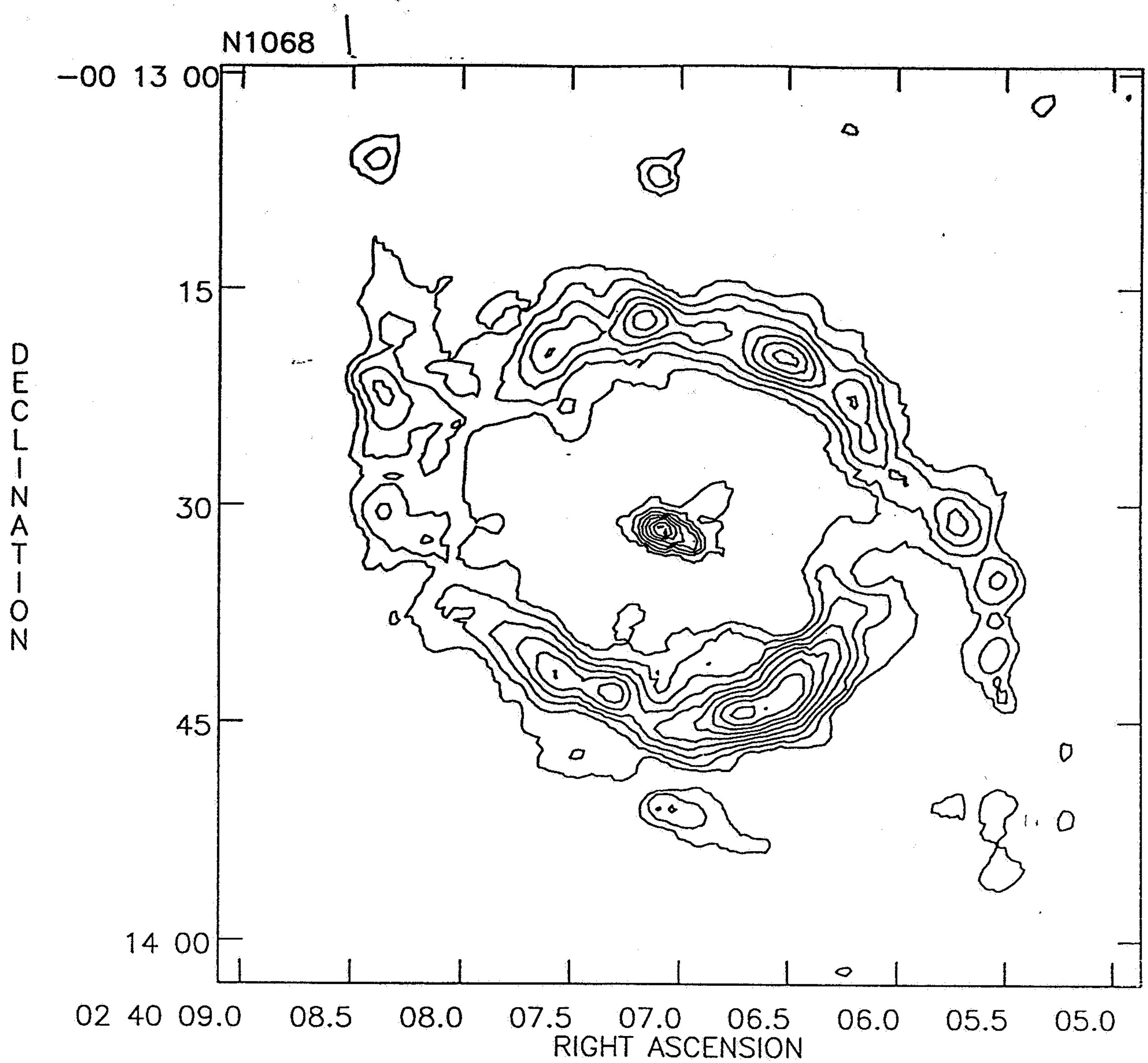

Fig. 1. Contours of the integrated CO emission mapped by the interferometer at $2.9'' \times 2.9''$ resolution. The lowest contour and the contour interval are 5 Jy km s^{-1} per beam. Emission at the nucleus includes radiocontinuum.